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Influence of back pressure of ink cartridge on regular operation of ink supply system

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ABSTRACT

The influence of back pressure of ink cartridge on regular operation of ink supply system was dealt with in the paper. In recent years, large ink supply system has developed a lot to increase the print usage of cartridge; however, the amount of back pressure in the cartridge may change very much when the cartridge would be equipped with ink supply system. It might further result in different printing behavior of cartridge in the printer. It's much of interest in the study. Therefore, experiments were done to determine what influence might occur in one specific test system. It was found that ink droplet, nozzle firing, and print quality were significantly influenced over the time of ink supply. The experimental result was helpful in future design of ink supply system.

Keywords: Back pressure, Ink cartridge, Ink supply system, Ink-jet printer

1. INTRODUCTION

As the amount of print load on every ink-jet printer was getting larger, one large ink supply played a more important role than ever before. Meanwhile, several ink supply systems were already presented for the past years^{1, 2, 3}. With these systems, the print usage of ink cartridge/print head could increase over a few times than ever before. However, some disadvantages related to the pressure stability of printhead might be induced⁴. It's recalled that the ink could be kept with no drilling in the printhead partly because a negative back pressure had to be successfully set up in the ink cartridge. Different back pressures might make difference of print thereof. Since the ink cartridge was connected to ink supply system, the three ones (cartridge, supply system, and print) could be related closely. The close relationship was illustrated in Figure 1.0 as follows.

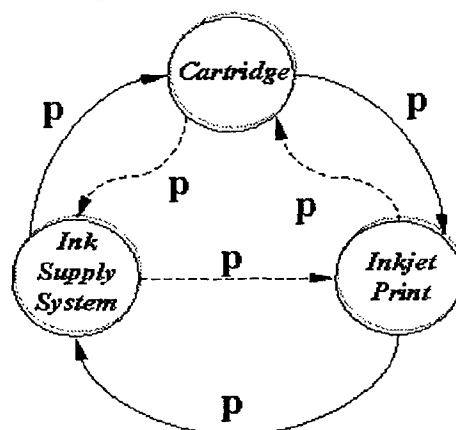


Fig. 1.0: Close relationship among ink cartridge, ink supply system, and inkjet print

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We noticed that the pressure of ink, symbolized P , connected all of them together via any necessary tubing system. Any change of pressure in every one would create a signal of pressure wave to its neighbors in either clockwise direction (solid lines) or counterclockwise direction (dashed lines) of Figure 1.0. Therefore, it's expected to find the interactive effects in the study. In addition, we can carefully deal with the relationship by a simple mathematical model, as shown in Figure 2.0. Assumed here that any two among the ink cartridge, supply system, and inkjet print were symbolized of S_1 and S_2 (meaning the states). Next, there would be two possible statuses between S_1 and S_2 . One was 'standing status' that no ink was moving between the two states. In standing status, the pressures of two states must be equal, illustrated in equation (1). The other was assigned as 'flowing status' that ink was flowing from one state to another. No doubt, ink would always flow from high pressure state to low pressure state, expressed in equation (2). It's noticed that the flowing pressure loss should be taken into account mainly due to friction of motion.

$$P_{(S_1)} = P_{(S_2)} \Leftrightarrow \text{standing} \quad (1)$$

$$\begin{cases} \text{if } P_{(S_1)} + P_{loss} > P_{(S_2)}, \text{ then } S_1 \rightarrow S_2 \\ \text{if } P_{(S_2)} + P_{loss} > P_{(S_1)}, \text{ then } S_2 \rightarrow S_1 \end{cases} \Leftrightarrow \text{flowing} \quad (2)$$

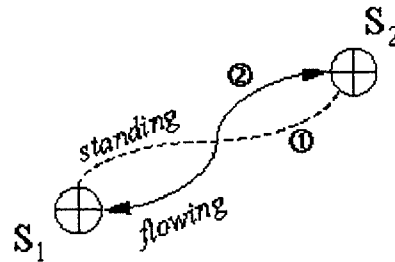


Fig. 2.0: Possible standing or flowing status between any two states

2. EXPERIMENTS

2.1 Test System Setup

One test system was set up to do the experiments, which composed of ink supply system, ink cartridge, etc., listed in the Table 1.0. Note that the cartridge was reconstructed for being able to obtain specific connection with the ink supply system.

① Ink	Pelikan Black Ink (water-based) with <i>Surface tension</i> = 48 dyne/cm, <i>Viscosity</i> = 2.35 cps = $2.35 \times 10^{-1} \text{ N.S/m}^2$
② Ink Supply System	◆ Rigid container with <i>Maximum capacity</i> = 375 cc <i>Length x Width x Height</i> = 62 x 46 x 134 mm
	◆ Tubing system (Silicone Tube) with Φ (outer) x Φ (inner) = 2 mm x 4 mm, <i>Total length</i> = 1700 mm
	◆ Guide (Flap Open and Close Type) with <i>Total length</i> = 900 mm (45 links, where one link = 20mm) <i>Width</i> = 27 mm, <i>Height</i> = 12 mm
③ Ink Cartridge	HP51645A <i>Length x Width x Height</i> = 50 x 15 x 70 mm <i>Maximum capacity</i> = 53 ml, <i>Weight with no ink</i> = 53. g <i>Weight with full ink</i> = 106 g

Table 1.0: Key parts of test system in the experiments

2.2 Experimental Procedures

First of all, the ink cartridge was filled with full ink of volume $V1$. The reservoir of supply system contained ink of volume $V2$ at the level of height H . Next, the cartridge was located at the vertical position where's lower h than that of the reservoir. The reservoir of system was simply open to the environmental air and yield $P3$ of one atmosphere. It's critical here that the value of h should be less enough than the value of H to obtain a negative back pressure of $P1$ and $P2$ in the cartridge. Thus, the integrated test system could be running for print on the regular operation of inkjet printer. Secondly, having the system integrated, the experimental procedures were followed as shown Figure 3.0. It illustrated that the cartridge was driven to print with reservoir height of H ; of course, the H was decreasing over time. Then the reservoir would not be refilled to the full position H until the ink was low and almost running out. And repeated another print and stopped when the ink was low again.

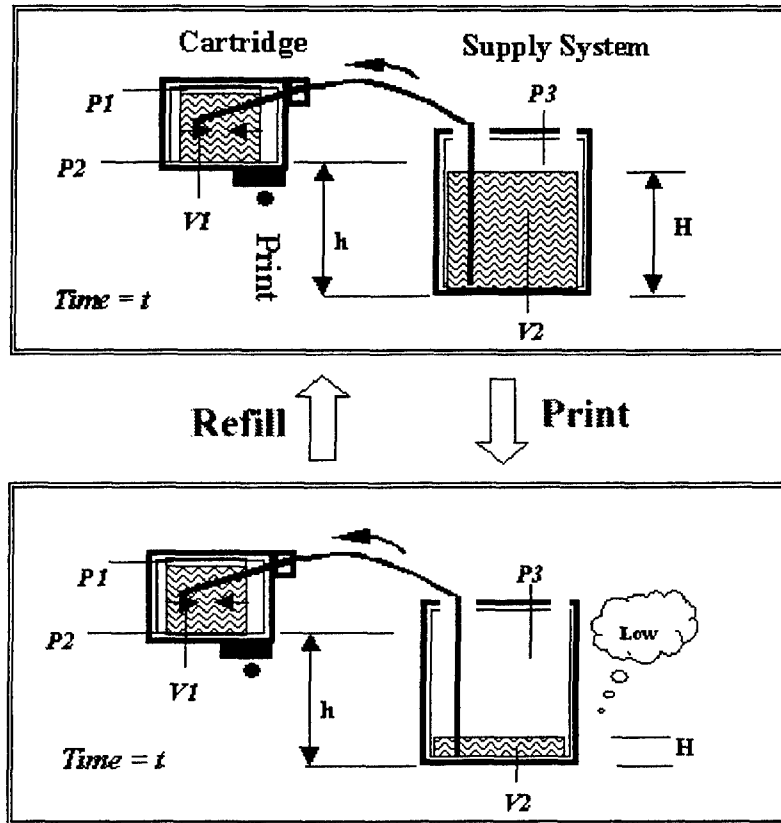


Fig. 3.0: Experimental procedures for the test system

Meanwhile, the initial conditions of the above experimental procedures were listed as below too. Consequently, all the results of print were measured and taken a record to find out the influence of back pressure on the operation of supply system. It's noted that all we concerned much would be the pressures $P1$ and $P2$ associated with the height of ink reservoir H in the system.

$$\begin{cases} P3 = 1 \text{ atm} = \text{constant} \\ h = 12.3 \text{ cm} \\ H = 10.5 \text{ cm} \end{cases} \quad \Leftarrow \text{initial conditions at Time } t = 0$$

3. EXPERIMENTAL RESULTS

3.1 Print History

The test had used A4 size of white paper as media in the print, which the printing pattern was simply a full-page black rectangle. As a result, total 680 pages (sheets) were printed on the two times of print and refill, noting that each time exactly finished 340 pages, respectively. The inking and pressure histories were recorded as below.

3.1.1 Inking history

Inking history meant that the volume of ink left in ink reservoir, as be on printing, were measured once for every 20 pages. Therefore, the volume of ink versus page number could be simply taken a record as shown in Figure 4.1.

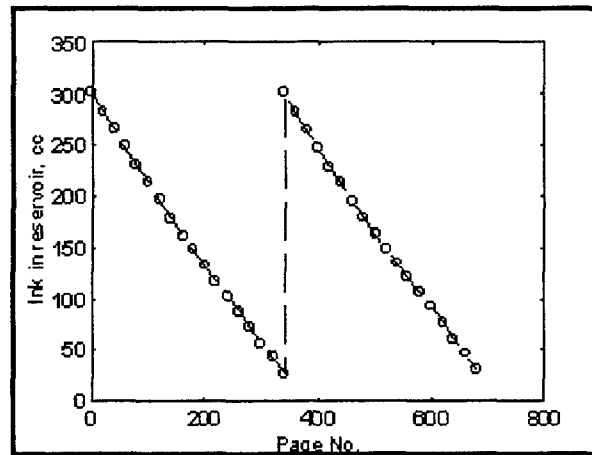


Fig. 4.1: Inking history of experiment

3.1.2 Pressure history

Pressure history meant that the pressure status of ink cartridge, as be on printing, were measured once for every 20 pages too. Noted that pressure P1 of top position and pressure P2 of bottom position were necessary to be taken. As a result, the pressures versus page number could be recorded as illustrated in Figure 4.2.

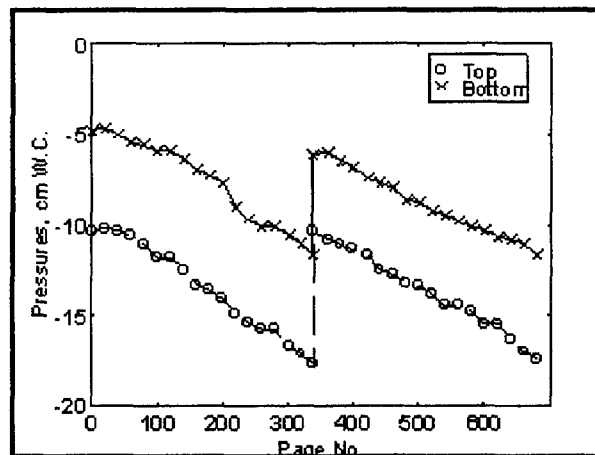


Fig. 4.2: Pressure history of experiment

3.2 Transformation to Change

The information of print history could be transformed into the change of corresponding properties. It's recalled here that what had be much concerned would be the situations of ink usage and pressures as the system working on every print. Hence, it's truly significant to make such a transformation as below.

3.2.1 Change of ink usage

By applying the result of print history shown in Figure 4.1, the change of ink usage for every 20-page print could be calculated in the transformation. The result was illustrated in Figure 4.3. It was given with an average ink usage of 0.8 cc in the print history. In addition, with the printing resolution and coverage, an average drop size of ink was yielded of 36.72 pl. The two dashed lines A and B would be further discussed later in next sections.

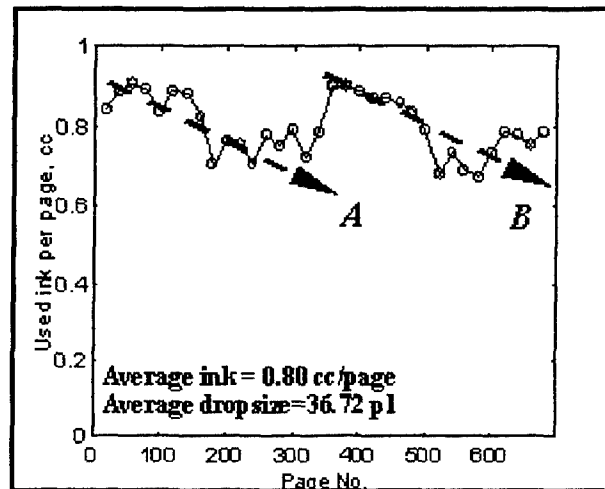


Fig. 4.3: Change of ink usage for the print

3.2.2 Change of pressures

In the mean time, it's also concerned a lot that the relationship should be existing between the change of pressures in the reservoir and in the cartridge of head. By using the information in Figure 4.2, the relation was found as shown in Figure 4.4.

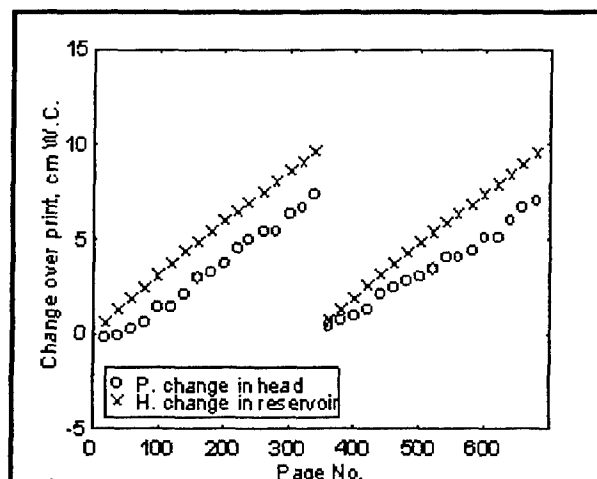


Fig. 4.4: Change of pressures in ink cartridge (head) and reservoir of supply system

3.3 Firing and Stability

It's reminded that the firing situation of nozzle and the stability of system might effect print quality. Simply printing one nozzle test pattern given in the test system of printer could check out the firing situation. Additionally, the stability of system could be defined as what change might be occurring during a long enough time.

3.3.1 Firing situation of nozzle

Failure of nozzle (see symbol '*' in Figure 4.5) might happen in the print. It had been checked by means of nozzle test print for every 100-page print. On the other hand, the equivalent amount of bad nozzles (see symbol 'x' in Figure 4.5) could be figured out in average way by transformation of Figure 4.3 where maximum usage represented 100% good nozzles and the rest was compared to it.

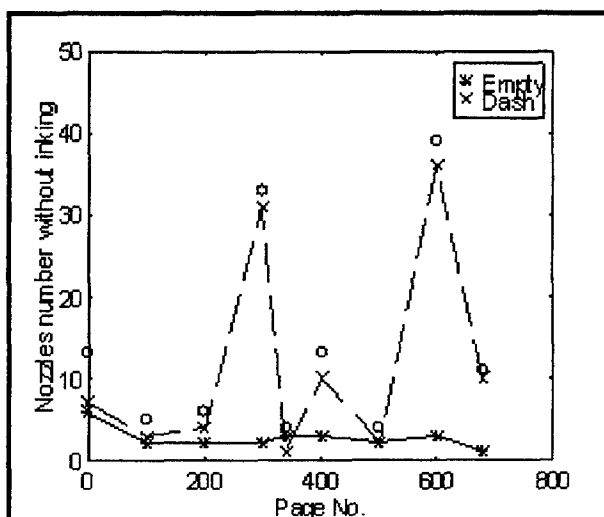


Fig. 4.5: Situation for failure and bad performance of nozzle in the print

3.3.2 Stability of system

By above definition, the changes of weight in reservoir and pressure in head were recorded during a period of 12 hours, as shown in Figure 4.6.

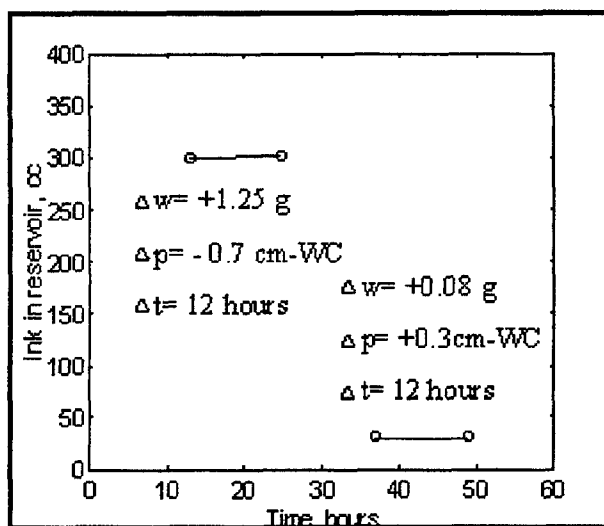


Fig. 4.6: Stability of system in the print

4. DISCUSSION OF RESULTS

It's so obvious that the repeatability was pretty well in the two times of print and refill. This proved test system working fine. Thus, the influence of back pressure of ink cartridge on supply system had been seen clearly as follows. First of all, the back pressure of reservoir was simultaneously getting lower and lower as the pressure of ink cartridge was decreased (see Figure 4.2). The effect could be clearly explained in the previous equation (1). In physical point of view, the ink consumption of inkjet print sent a signal of pressure wave to cartridge and subsequently made a change of pressure in the cartridge. Following the pressure change of ink cartridge, the cartridge forwarded the signal to ink supply system and made a pressure change of supply system too. The Figure 1.0 could successfully explain this inside of experimental results. Additionally, the process would not stop until any two states of them had reached complete equilibrium, as described in Figure 2.0.

Secondly, the degree of effect could be defined in two aspects. One of them was to see how much change of pressure in cartridge might be caused by the change of pressure in reservoir. It's noted here that the cartridge HP51645A had a leaf spring acting as a pressure regulator. This regulator could eliminate some percentage of pressure change in reservoir. It's found in the experimental results that roughly 20-30% of pressure change might be eliminated. The other aspect was to check how much change of ink usage per page might be induced from the change of pressure in reservoir. Figure 4.3 had already obviously shown that the ink usage per page was decreasing from about 0.9 cc down to about 0.7 cc over time. The solid lines A and B in the Figure 4.3 clearly indicated the tendency in the direction of arrowhead. Noted that most of nozzles has no failure in the history (see Figure 4.5). Therefore, the tendency in decreasing might imply that the size of ink droplet had made difference over the time of print. The amount of change could be estimated in further calculation if the size changed. Of course, it could create some problems of print quality⁵.

Finally, the term of effect had been explored in the experiment. The experimental results had shown that any two states could keep quite stable during a period of 12 hours (see Figure 4.6). Of course, the state might take much less time than 12 hours to reach stable. If the period were shortened a lot, then one of the paths ① and ② shown in Figure 2.0 would make difference in the effect. It could be further explored in the future study.

5. CONCLUSION

Influence of back pressure of ink cartridge on regular operation of ink supply system was studied in the paper. Physical concept for the influence was first presented and described in the aspects of pressure wave. Mathematically, some equations were given to predict the possible solutions of the effect. Thus, some experiments had been done to figure out the close relationship among the ink cartridge, ink supply system, and inkjet print. As a result, it's found that a signal of pressure wave should actually exist to connect each other. Consequently, the pressure change of ink cartridge had been simultaneously caused by the change of ink reservoir in the same way. In the mean time, the ink consumption per page of print had also been influenced with obvious tendency. More precisely, it's decreasing downward too when the pressure of cartridge was decreasing. Thus, some print quality might occur. The experimental results had met well with the prediction of physical models and mathematical equations.

In the future, further work could be explored on the effects of print quality, including ink droplet size, possible transformation in real time response of pressure, and so on. More interesting results in those aspects would be found and further help the future design of ink supply system.

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